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SUBJECT: Pressure in the Saturn I Workshop
During Orbital Storage - Case 610

DATE: July 3, 1969

FROM: T. C. Tweedie, Jr.

ABSTRACT

The pressure decrease in the spacecraft modules of the Saturn I Wet Workshop is estimated as a function of the unmanned storage time in orbit. Based on specification leak rates of the gaseous atmosphere, the pressure in the OWS drops from 5.0 psia to 0.5 psia in about 200 days; the pressure in the MDA, which is isolated from the OWS, drops from 5.0 psia to 2×10^{-6} psia (10^{-4} torr) in about 60 days.

(NASA-CR-106418) PRESSURE IN THE SATURN I
WORKSHOP DURING ORBITAL STORAGE (Bellcomm,
Inc.) 10 p



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MEMORANDUM FOR FILE

Following the manned AAP-1/2 mission, the Saturn I Wet Workshop is stored in orbit for about two months before reactivation by the next AAP mission. During the quiescent storage period, the atmosphere in the pressurized volume leaks out to space and is not replenished resulting in a loss of pressure. To plan for possible deleterious effects on the equipment which is installed in the Workshop, the pressure decrease is estimated as a function of storage time.

The Saturn I Workshop is composed of three modules: the Multiple Docking Adapter (MDA), the Airlock Module (AM), and the S-IVB. During the storage period, the SIWS is divided into three separate volume elements by the two closed hatches in the Airlock Module. The first volume element is the MDA and the top of the AM, the second is the airlock itself located in the middle of the AM, and the third is the bottom of the AM plus the liquid hydrogen tank of the S-IVB (the Orbital Workshop [OWS]) which have been converted to crew living space. Since equipment is stored in both the OWS and the MDA the pressure loss in them during orbital storage is calculated.

The flow of gas from a pressurized vessel into a region of lower pressure varies with the pressure and the size of the hole. For a hole size large compared with the mean free path in the gas and a large pressure difference, the velocity of the issuing gas is limited by the speed of sound in the gas. In this case, treated by fluid mechanics, the mass flow through a given size hole is proportional to the upstream (higher) pressure. If the hole size is small compared to a mean free path, gas molecules issue independently and kinetic theory of gases is applicable.

OWS

In the case of estimating the decrease in pressure in the OWS during orbital storage, rigorous modeling of the sizes and shapes of the holes can be avoided by using the

established specification leak rate. The specification⁽¹⁾ on the LH₂ tank sealing devices requires that the total leakage from the LH₂ tank, including hatch adapter, be limited to 5 lbs mass per day when the workshop atmosphere is 100 percent oxygen at 6.2 psia, the maximum relief pressure. The 5 lbs/day corresponds to 0.43×10^{26} molecules/day leaking out. At 6.2 psia, the 10,460 ft³ habitable volume of the OWS plus the 90 ft³ of the connector and aft portion of the AM contain 3.6×10^{27} molecules. Assuming a Maxwellian distribution of particles, the mean free path is 1.5×10^{-5} cm. The actual atmosphere in the SIWS is a mixture of oxygen and nitrogen, carbon dioxide and water vapor, and trace contaminants from outgassing materials in the spacecraft. However, for the purpose of estimating the pressure decrease, the total atmosphere is assumed to be oxygen.

The mass flow and hence the change in the number of molecules, dn , in a unit time dt , under these conditions is proportional to the number present.

The change in the number of molecules in a unit time dt , is then

$$dn = -An_1 dt$$

Integrating

$$n_1 = n_o e^{-At}$$

The constant A can be evaluated at $t = 0$ from the known flow rate.

$$\frac{dn}{dt} = -An_o = -0.43 \times 10^{26} \text{ at } t = 0$$

$$A = 1.2 \times 10^{-2} / \text{day}$$

Thus

$$n_1 = n_o \exp (-1.2 \times 10^{-2} t)$$

Noting that the instantaneous pressure P_1 in the tank is proportional to the number of molecules present, n_1

$$P_1|_{\text{OWS}} = P_o \exp (-1.2 \times 10^{-2} t)$$

where

P_0 = initial pressure

t = time in days

The pressure P_i , plotted as a function of time in days, is shown in Figure 1 for an initial pressure of 5.0 psia with a slope of the curve on the semi-log plot being 1.2×10^{-2} /day. The pressure decreases from 5 psia, the nominal pressure in the OWS, to 1 psia in about 130 days and reaches 0.5 psia in 200 days. In the planned 60-day orbital storage period between the end of the AAP-1/2 mission and the beginning of the AAP-3A mission, the pressure will drop from 5 psia to about 2 psia. At a pressure of 0.5 psia the mean free path of the molecules has lengthened to 1.8×10^{-4} cm, which is still likely to be either small compared to a hole size or of the same order. At lower pressures and longer mean free paths, a shift to kinetic theory will be needed to predict further pressure decrease. As the pressure becomes small, outgassing from the equipment in the OWS contributes to the local environment and must be considered in the pressure determination.

MDA

The flow of the gaseous atmosphere from the MDA volume during orbital storage is substantially faster than from the OWS. At 5.0 psia the total number of molecules in the 1508 ft³ combined volume of the MDA, MDA/AM interface, STS, and forward section of the AM, is 4.1×10^{26} molecules. The mean free path at 5.0 psia is 1.8×10^{-5} cm. The leak rate specification⁽²⁾ for the MDA alone is 4 lbs/day at 5.0 psia and the Martin Marietta Corporation estimates that the leak rate from the combined volume is 6.77 lbs/day⁽³⁾. These leak rates correspond to 0.34×10^{26} and 0.58×10^{26} molecules/day respectively. Following the same procedure shown for the case of the OWS, the pressure in the MDA combined volume using the 6.77 lbs/day leak rate is given by

$$P_{MDA} = P_0 \exp [-14.3 \times 10^{-2}t]$$

where $P_0 = 5.0$ psia

and t = time in days

This equation, plotted as a function of time in days, is shown in Figure 2 starting with an initial pressure of 5.0 psia (254 Torr). A leak rate of 6.77 lbs/day produces a three order of magnitude decrease in pressure in about 50 days. For a pressure decrease by a factor of 1000, the mean free path has increased to 1.8×10^{-2} cm; further pressure below this region drop must be estimated from kinetic theory.

From the kinetic theory of gases it can be shown that the pressure in a vessel which slowly leaks gas is given by

$$P = P_0 \exp \left[-\frac{A\bar{v}}{4V} t \right]$$

where

A = area of the hole

\bar{v} = average velocity of the gas molecules

V = volume of the vessel

The exponent can be evaluated using the MDA volume, the average gas velocity corresponding to 70°F plus the equivalent area of the leak path. The exponent will give the slope of the pressure versus time curve but the exact sizes of the holes are needed to determine the region in which the shift from hydrodynamic flow to molecular flow occurs.

To bound the problem, the diameter of the total equivalent hole which leaks the atmosphere can be obtained from the equation of mass flow through a nozzle limited by the speed of sound at the throat⁽⁴⁾.

$$\dot{m} = \sqrt{\frac{k}{RT_0}} P_0 A^* \left[1 + \frac{k-1}{2} \right]^{-\frac{k+1}{2(k-1)}}$$

where

k = ratio of the specific heats = 1.4

R = gas constant

T₀ = gas temperature

P₀ = tank pressure

A* = area of nozzle throat

Substituting initial values of 6.77 lbs/day mass flow rate at 70°F, from a 5.0 psia reservoir in this equation yields a throat size of $2.4 \times 10^{-2} \text{ cm}^2$. Thus the total mass flow is equivalent to that from a single hole about 0.175 cm in diameter. If the single hole is replaced by many smaller holes, keeping the total area constant, the total flow remains constant* but the transition region between the two flow regimen is shifted. Using the area of the hole as $2.4 \times 10^{-2} \text{ cm}^2$, the exponent for the pressure decay becomes 0.55/day. Thus in the low pressure range the pressure would be given by

$$P = P_0 \exp [-0.55 t]$$

The point at which this equation becomes applicable cannot be determined without exact knowledge of how the total equivalent hole area is divided among the many leak paths. For the purposes of comparison, the total area is apportioned among 10^2 , 10^3 , 10^4 , holes which leads to hole diameters of $1.75 \times 10^{-2} \text{ cm}$, $5.54 \times 10^{-3} \text{ cm}$, and $1.75 \times 10^{-3} \text{ cm}$ respectively. When the mean free path in the gas is of the same order of these size holes then the equation for kinetic theory is applicable. Shown on Figure 2 is the effect of these three possible distribution of hole areas. It is seen that the pressure will have dropped to the 10^{-4} torr range in from 50 to 75 days depending on the number of leak paths. Below this pressure, outgassing from the materials stored in the MDA may limit the rate of further pressure decrease. The final pressure limit in the MDA is the ambient external pressure, which at 200 nm is about 4×10^{-8} torr.

It should be noted that in the high pressure region the flow rate and hence pressure decrease is limited by the speed of sound at the exit orifice. If this physical limitation did not occur, then the flow rate and pressure decrease would be derived from kinetic flow. As the number of molecules in the tank decreases the conditions for sonic flow are no longer present and the flow and corresponding pressure decrease approaches the free molecular value. The estimated transition region between these two models is shown as dotted lines on Figure 2.

*This neglects viscous effects at the hole boundary which may modify the flow and somewhat change the flow rate.

Conclusions

Assuming that the OWS leaks its O_2/N_2 atmosphere at the specification leak rate of 5 lbs/day during unmanned orbital storage, the pressure will decay from 5 psia to 0.5 psia in about 200 days. In the contemplated storage period of 60 days, the pressure will decrease to about 2.5 psia. Equipment that is operated in the OWS at 5 psia should not suffer any deleterious effects when the pressure is cut in half.

The MDA, leaking atmosphere at 6.77 lbs/day, experiences a pressure reduction from 5 psia to 0.05 psia in about 20 days. For longer storage periods, further pressure decrease can only be estimated since the number and sizes of the leak paths are unknown. As a bound on the problem, the pressure in the MDA after about 60 days of orbital storage can be expected to be in the 10^{-4} torr (2×10^{-6} psia) range. Thus equipment that is scheduled to be located in the MDA during orbital storage should be built to withstand low pressure.

T. C. Tweedie Jr.

T. C. Tweedie, Jr.

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Attachments

References

(1) Contract End Item Detail Specification for S-IVB/IB Saturn Workshop Accessory Kit, paragraph 3.3.1.6.1, McDonnell Douglas Astronics Company, Huntington Beach, California, January 11, 1969.

(2) End Item Specification on the MDA, MSFC CP114 A 100026C, September 4, 1968.

(3) "Reactivation Pressure Integrity Check," Martin Marietta Corporation Report ED-2002-526-2, October 23, 1968.

(4) Hansen, Arthur G., Fluid Mechanics, John Wiley and Sons, Inc., 1967.

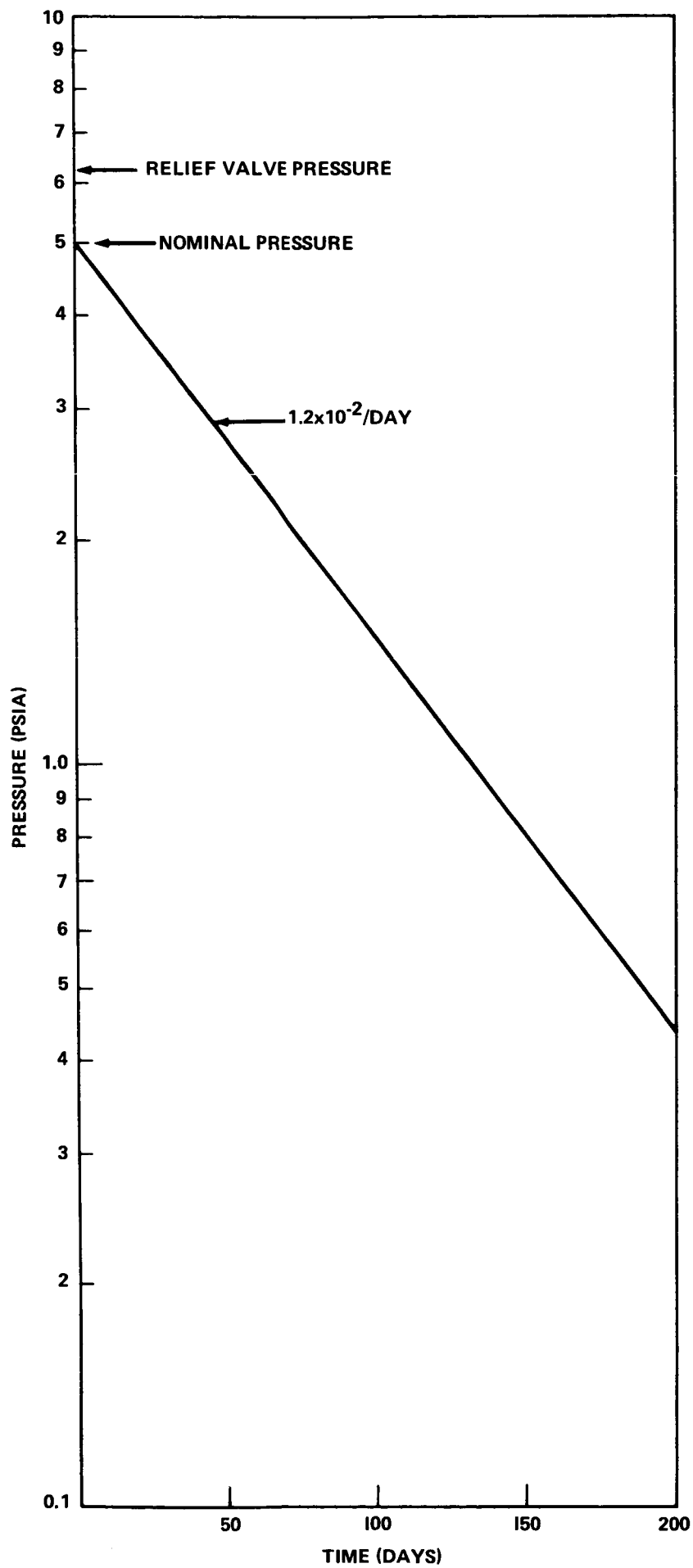


FIGURE 1- PRESSURE IN THE OWS VERSUS TIME

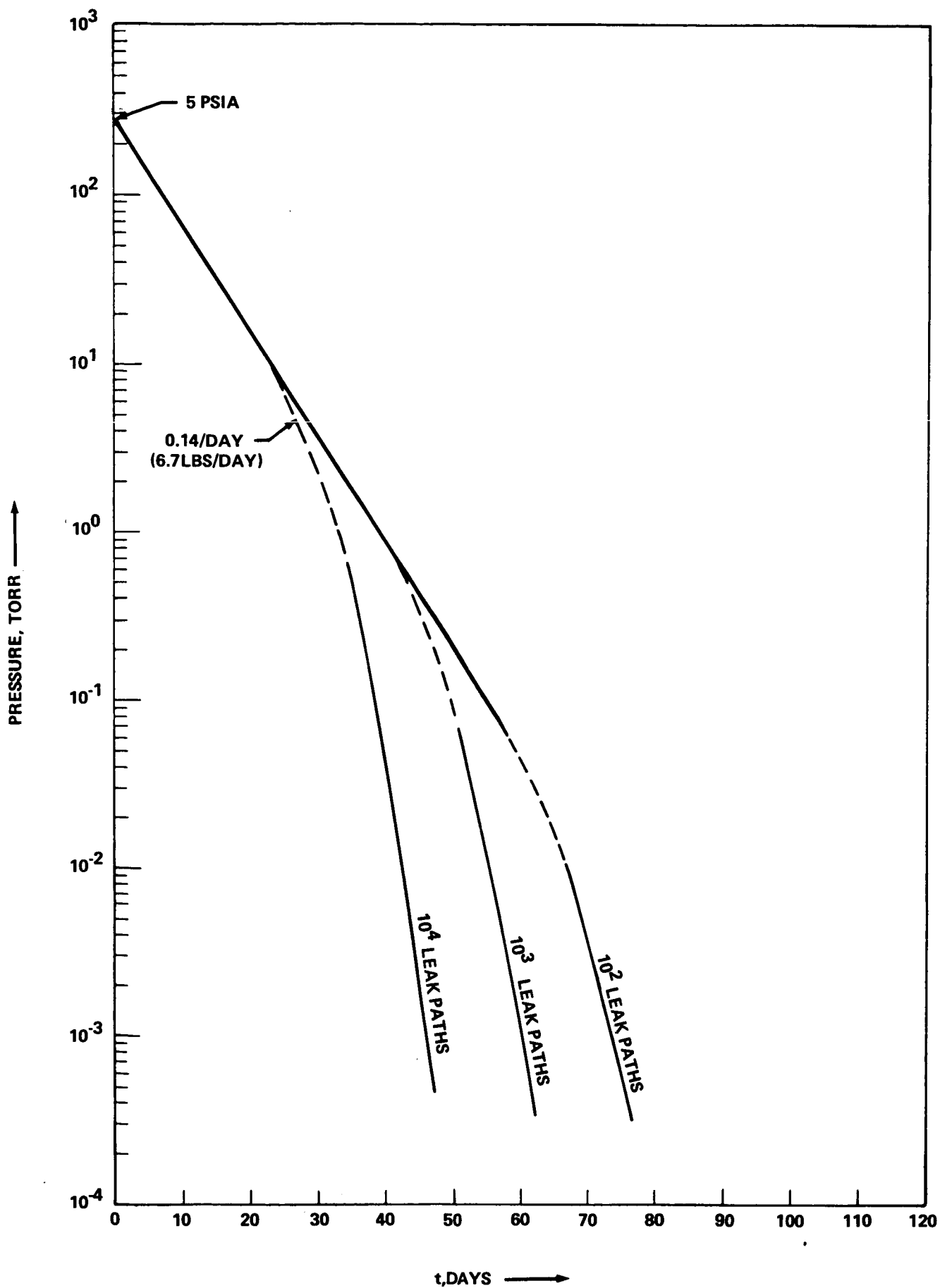


FIGURE 2- PRESSURE IN THE MDA UNIT VOLUME VERSUS TIME

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